

Stellar Orbits in Barred Galaxies with Nuclear Rings

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Abstract. We investigate the dynamical response of stellar orbits in a rotating barred galaxy potential to the perturbation by a nuclear gaseous ring. The change in 3D periodic orbit families is examined as the gas accumulates near the inner Lindblad resonance. It is found that the x_2/x_3 loop extends to higher Jacobi energy and a vertical instability strip forms in each family. These strips are connected by a symmetric/anti-symmetric pair of 2:2:1 3D orbital families. A significant distortion of the x_1 orbits is observed in the vicinity of the ring, which leads to the intersection between orbits over a large range of the Jacobi integral. We also find that a moderately elliptical ring oblique to the stellar bar produces significant phase shifts in the x_1 orbital response.

About 2/3 of all disk galaxies are weakly or strongly barred (de Vaucouleurs 1963), many more are ovally distorted (Bosma 1981; Kormendy 1982) or have triaxial bulges (Kormendy 1994). Central starburst activity in these galaxies often delineates $\sim \text{few} \times 100$ pc size ring-like structures of star forming regions mixed with molecular gas and dust (Buta & Crocker 1993). Nuclear “rings” seem to be associated with inner Lindblad resonances (ILRs) (Telesco & Decher 1988; Shlosman *et al.* 1989; Kenney *et al.* 1992; Athanassoula 1992; Knapen *et al.* 1995a,b). Their intrinsic shapes vary from circular to moderately elliptical, in which case they lead stellar bars by $\sim 50 - 90^\circ$. As such, nuclear rings are moderately strong perturbations on the gravitational potential of the central galactic region, thus affecting stellar orbits and gas flow there. We analyze the main stellar orbits (in the plane and 3D) in the presence of a ring (see also Heller & Shlosman 1995).

The galaxy model consists of the superposition of four components: disk, bulge, bar, and ring. The disk is represented by a Miyamoto-Nagai potential, the bulge by a Plummer sphere, and the bar by a triaxial Ferrers density distribution. The ring is centered in the ILR region and for the models presented here is equivalent to $\sim 10^9 M_\odot$ or 38% of the local mass (Model D).

The characteristic diagram for the main planar prograde periodic orbits in the inner region of the model when no ring is present (Model A) is shown in the upper frame of Figure 1. The three direct families x_1 , x_2 , and x_3 are shown along with two vertical instability strips. From the vertical instability strips bifurcate pairs of symmetric/anti-symmetric 3D orbital families, 2:2:1

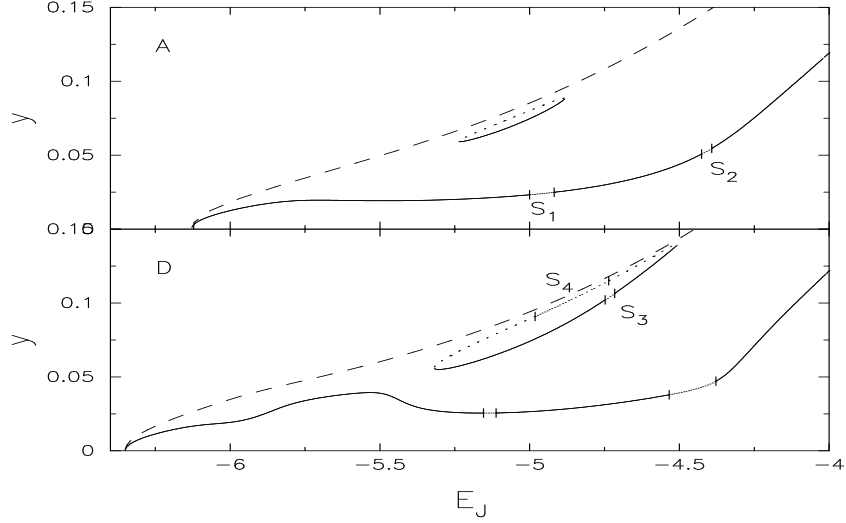


Figure 1. Characteristic diagrams of the x_1 , x_2 , and x_3 families for models without (A) and with (D) a nuclear ring. Stable sections of the characteristics are represented by solid lines while unstable are broken. Four vertical instability strips are marked. The long-dashed curve is the zero velocity curve.

(BAN/ABAN) and 2:3:1 families from S_1 and S_2 , respectively. The 2:3:1 families have interesting orbital shapes that are symmetric about one vertical plane while being anti-symmetric about the corresponding perpendicular vertical plane.

As the mass of the ring is increased a “bump” in the x_1 family forms and broadens at an E_J below the ILR. This distortion represents a local maximum in the y -extent of the orbits, resulting in a large region of the x_1 family to have orbits that intersect with other x_1 orbits at higher E_J . Such orbit intersections also occur in the x_2 family as a local maximum in orbit eccentricity develops along the sequence. Also, as the ring’s mass is increased the region of stability close to the plane of the 2:2:1 symmetric family increases while the x_2/x_3 loop extends to higher E_J and develops two regions of vertical instability. These two instability strips, one on x_2 and one on x_3 , are connected by a symmetric/anti-symmetric pair of 2:2:1 families elongated perpendicular to the stellar bar. The symmetric family is stable over half of its characteristic, while the anti-symmetric is unstable everywhere. The bottom frame of Figure 1 shows the planar characteristic diagram for the model with a circular ring and indicates the location of the x_2/x_3 instability strips S_3 and S_4 .

In Figure 2a we show the phase shift or twisting of the x_1 orbital alignment in response to a moderately elliptical ($e = 0.4$) ring leading the stellar bar by 60 degrees. The change in ellipticity and position angle is given in Figure 2b and is compared with models A and D. It can be seen that while the eccentricity as a function of E_J is only slightly offset from the circular ring case, the position angle of the orbit semi-major axis swings from -10 to 35 degrees with respect to the bar. Note, that innermost x_1 orbits trail the bar. The interior orbits remain stable and continue to trap a significant region of phase space around them.

The main effect of the circular nuclear ring is to produce intersecting orbits over a wide range of Jacobi energies in both the x_1 and x_2 orbit families. Gas on such orbits will shock and dissipate energy on a dynamical time scale. As a

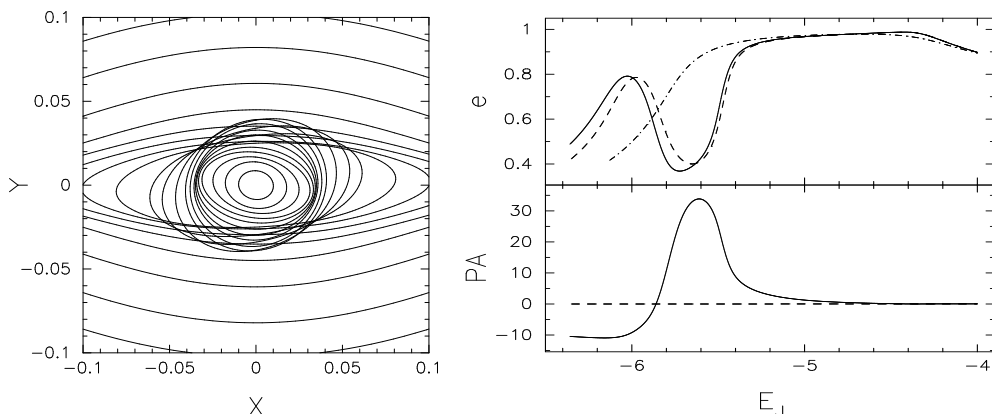


Figure 2. (a) Twisting of x_1 orbits in model with oblique elliptical ring. The ring with an ellipticity of 0.4 and semi-major axis 0.04 units is leading the bar by 60 deg. The frame is 2 Kpc on a side. (b) Eccentricity and position angle of x_1 orbits from models without ring (dot-dashed), with circular ring (dashed), and oblique elliptical ring (solid), as a function of the Jacobi energy.

consequence, the gas will quickly settle down deep inside the resonance region, further enhancing the ring. The growth of the ring is limited by its self-gravity. For a non-circular ring oblique to the stellar bar and leading it, the twisting of the x_1 orbits will further enhance shocks in the gas. It is clear from Figure 2, that both trailing and leading shocks will develop.

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